Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Revision of Part 15 of the Commission's Rules	)	ET Docket No. 98-153
Regarding Ultra-Wideband Transmission	)	
Systems	)	

DOCKET FILE COPY ORIGINAL

RECEIVED

SEP 12 2000

FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

To the Commission:

COMMENTS OF CISCO SYSTEMS, INC.

Bruce Mehlman
Telecommunications Policy Counsel
Cisco Systems, Inc.
601 Pennsylvania Ave., N.W.
Suite 520 – North Building
Washington, DC 20004
(202) 661-4006

Philip L. Malet
Todd B. Lantor
Steptoe & Johnson LLP
1330 Connecticut Avenue, N.W.
Washington, DC 20036
(202) 429-3000

Counsel for Cisco Systems, Inc.

Dated: September 12, 2000

No. of Copies rec'd 0+4
List A B C D E

SUMMARY

Cisco Systems, Inc. ("Cisco") hereby submits its comments in response to the *Notice of Proposed Rulemaking* ("*NPRM*") in the above-captioned proceeding. In its *NPRM*, the Commission proposes to amend Part 15 of the Rules to facilitate the introduction of products incorporating ultra-wideband ("UWB") technology. As a leader in the development of fixed wireless communication technologies for the computer networking and Internet service markets, including systems in the MMDS and ITFS bands, Cisco has a vital interest in this proceeding.

Cisco has serious concerns that the specific rules outlined in the *NPRM* allow for UWB devices that would interfere with existing, licensed radio communications services, such as MMDS/ITFS operations in the 2150-2162 MHz and 2500-2690 MHz bands, and that could negatively impact the public. Such a result would contradict the policy objectives of Chairman Kennard who, earlier today, stated: "[M]y top priority at the FCC is to get high-speed broadband access into every home and hamlet in this country." Therefore, Cisco recommends that the Commission carefully consider these interference issues and await testing of actual UWB devices with commercial radio systems before issuing any final rules in this proceeding.

As the Commission appropriately recognizes in its *NPRM*, UWB systems do not generally conform to the traditional model of spectrum management where finite bands are allocated to particular services. The structure of UWB signals is such that emission bandwidths are very large – typically over 1 GHz -- and overlap many different frequency allocations. UWB devices are also very different from the existing unlicensed intentional and unintentional radiators allowed under Part 15 of the Rules in that: 1) they will emit significant power over a large portion of the spectrum and, depending on the implementation, generate multiple spectral peaks over a very large range of frequencies; 2) their pulses potentially will have peak powers

that greatly exceed average powers; and 3) applications such as data networking and collision avoidance radar envisioned by proponents could lead to the proliferation of a very large number of UWB transmitters emitting signals at or near permitted limits. In light of these unique operating characteristics, the regulation of UWB technologies must be based on a sound theoretical framework and verified by comprehensive testing against all likely victim radio systems, including advanced broadband wireless MMDS receivers.

Much of the basic analytical approach used by Cisco in its analysis of UWB interference effects on MMDS networks is reflected in the analysis set forth in the submission of the Wireless Information Networks Forum ("WINForum") in response to the Commission's *Notice of Inquiry* in this proceeding. Based on this analysis, it is apparent that the existing general emission limits for Part 15 Class B devices are inadequate to protect wideband receivers (such as those used in MMDS networks) from harmful interference caused by UWB transmitters. Instead, the Commission should develop interference protection rules based upon the **energy spectral density** of the UWB transmissions which takes into account both the pulse size and the pulse repetition rate. As set forth in the attached materials, energy spectral density is a far better predictor of interference into victim receivers than peak and/or average power levels of UWB signals.

In light of the analysis done to date on the potential for harmful interference from UWB devices to wideband communications systems, significant testing must be done before any interference protection rules can be adopted by the Commission. The Commission must avoid taking any action that would disrupt or displace incumbent MMDS licensees who are in the process of deploying advanced fixed wireless broadband services to many areas currently unserved and underserved by existing technologies.

TABLE OF CONTENTS

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems	)))	ET Docket No. 98-153

To the Commission:

COMMENTS OF CISCO SYSTEMS, INC.

Pursuant to Section 1.415 of the Commission's Rules,[1] Cisco Systems, Inc. ("Cisco") hereby submits its comments in response to the *Notice of Proposed Rule Making* ("*Notice*" or "*NPRM*") in the above-captioned proceeding.[2] In its *Notice*, the Commission proposes to amend Part 15 of the Rules to facilitate the introduction of products incorporating ultra-wideband ("UWB") technology. Cisco shares the Commission's desire to allow technological innovation to overcome problems of spectral congestion, and to provide the American public with multiple and competing high-speed methods of accessing the Internet.[3]

---

1 47 C.F.R. § 1.415 (1999).

2 *In the Matter of Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, Notice of Proposed Rule Making, ET Docket No. 98-153 (rel. May 11, 2000) ("*NPRM*").

3 *See Petition for Declaratory Ruling of Clarity Wireless, Inc.,* MM Docket No. 97-217 (Aug. 31, 1999) (Petition in which Clarity Wireless, Inc., since purchased by Cisco, requested that the Commission authorize the use of Vector Orthogonal Frequency Division Multiplexing digital modulation with respect to the provision of Multichannel Multipoint Distribution Service ("MMDS") and Instructional Television Fixed Service ("ITFS"). Through

(Continued ...)

Cisco is quite hopeful that UWB technologies might enable broadband applications such as indoor wireless local area networks and personal area networks, as well as provide precise measurement of distances or locations, obtain the images of objects buried underground or behind surfaces, and potentially improve the public's safety while driving. Cisco has serious concerns, however, that the specific rules outlined in the *NPRM* allow for UWB devices that would interfere with existing, licensed radio communications services and that could negatively impact the public. Accordingly, Cisco recommends that the Commission carefully consider these interference issues and await testing of actual UWB devices with other commercial radio systems before issuing any final rules in this proceeding.

I. INTRODUCTION

Cisco is a worldwide leader in the manufacture of networking equipment and has a vital interest in this proceeding. Its corporate goal is to maximize the number of people using the Internet over all technological platforms at the highest speeds and as quickly as possible. Cisco takes a largely technology-neutral approach and currently designs and builds products to enable broadband access over all available media – from cable and traditional wireline systems to emerging wireless systems – both fixed and mobile. With its purchase of Clarity Wireless, Inc. ("Clarity") in November 1998, Cisco became one of the leading developers of fixed wireless communication technologies for the computer networking and Internet service markets. The Vector Orthogonal Frequency Division Multiplexing ("VOFDM") technology initially developed by Clarity addresses the problem of providing high-speed, reliable operation in obstructed

---

VOFDM technology, wireless cable operators can achieve very high data rates in severe multipath conditions, thereby leading to revolutionary new uses for MMDS and ITFS spectrum).

environments, which have traditionally been challenging to wireless network communications. Among the many products it has developed (and continues to develop) are broadband fixed wireless services in the MMDS and ITFS bands. Combining MMDS/ITFS networks with its portfolio of other broadband access products, Cisco is able to offer "last mile" solutions for access to the Internet as well as other integrated voice, data and video applications.

The Commission must ensure that the introduction of UWB devices will not inhibit access to the Internet by causing interference to "last mile" delivery systems such as fixed wireless broadband technologies. Based upon its analysis to date, Cisco believes that the proposed UWB rules would allow harmful interference to threaten existing and planned broadband wireless services, especially MMDS/ITFS operations in the 2150-2162 MHz and 2500-2690 MHz bands. In this regard, it is imperative that the Commission follow through with the guiding principle that "any new rule provisions for UWB devices must ensure that licensed radio services are protected against interference."[4] Moreover, any action to the contrary would contradict the policy goals of Chairman Kennard who, earlier today, stated: "[M]y top priority at the FCC is to get high-speed broadband access into every home and hamlet in this country."[5] Cisco applauds the Commission for its assurances that, before adopting any final rules in this proceeding, it will provide interested parties with ample opportunity to complete testing and to ensure that analyses of the test results are submitted in the record for public comment.[6] In this

---

4 *NPRM* at ¶ 7.

5 "*Internet Telephony: America is Waiting*," remarks by FCC Chairman William E. Kennard, before the Voice Over Net Conference, Atlanta, Georgia (Sept. 12, 2000).

6 *Id.* at ¶¶ 1, 7, 31.

regard, Cisco agrees with the Commission's view that "[f]urther testing and analysis is needed before the risks of interference are completely understood."[7]

II. THEORETICAL FRAMEWORK FOR ANALYZING INTERFERENCE POTENTIAL OF UWB SYSTEMS INTO MMDS BROADBAND NETWORKS

As the Commission appropriately recognizes in its NPRM, UWB systems do not generally conform to the traditional model of spectrum management where finite bands are allocated to particular services.[8] The structure of UWB signals is such that emission bandwidths are very large -- typically exceeding 1 GHz -- and overlap many different frequency allocations. UWB devices are also very different from the existing unlicensed intentional and unintentional radiators allowed under Part 15 of the Rules in that: 1) they will emit significant power over a large portion of the spectrum and, depending on the implementation, generate multiple spectral peaks over a very large range of frequencies; 2) their pulses potentially will have peak powers that greatly exceed average powers; and 3) applications such as data networking and collision avoidance radar envisioned by proponents could lead to the proliferation of a very large number of UWB transmitters emitting signals at or near permitted limits. In light of these unique operating characteristics, the regulation of UWB technologies must be based on a sound theoretical framework and verified by comprehensive testing against all likely victim radio systems including advanced broadband wireless MMDS receivers that are operating and will operate in the 2150-2162 MHz and 2500-2690 MHz bands.

---

7 *Id.* at ¶ 1.

8 *Id.* at ¶¶ 3-4.

The proposed distinction drawn by the Commission in the interference potential of UWB devices operating below 2 GHz and above 2 GHz is not supported by Cisco's analysis. While the Commission expresses significant concerns about the operation of UWB devices in the region of the spectrum below approximately 2 GHz and therefore proposes more protective rules in that part of the spectrum, its analysis is somewhat flawed.[9] Many of the interference concerns that the Commission raises below 2 GHz apply equally to the frequency bands above that benchmark. It is simply incorrect to assert, as the Commission has done, that "UWB signals will quickly fall off below the background noise because of the high propagation losses at 2 GHz and above."[10] While the general theory that propagation losses of UWB signals will increase as signals move up in frequency is valid, there is not much of a difference between such losses at 2 GHz and 2.5 GHz – less than 2 dB. Nor is it correct to assume that "most radio services operating above 2 GHz use directional antennas that generally discriminate against reception of undesired signals."[11] When an interfering device falls in the beam of a directional antenna, the victim receiver will, in fact, experience a higher level of interference due to the antenna gain. Moreover, there are also a number of communications systems in place and on the drawing board that are operating and will operate soon with omni-directional antennas above 2 GHz, including MMDS, Mobile-Satellite Service, Wireless Communications Service, etc.

Much of the basic approach used by Cisco in its analysis of UWB interference effects on MMDS networks is reflected in the methodology set forth in the submission of the

---

9 *Id.* at ¶¶ 28-29

10 *Id.* at ¶ 27.

11 *Id.*

Wireless Information Networks Forum ("WINForum")[12] in response to the Commission's earlier *Notice of Inquiry* in this proceeding.[13] For ease of reference, a summary of WINForum's analytical framework is included in Attachment 1 to these Comments.

Based upon this analysis, the existing general emission limits for Part 15 Class B devices are clearly inadequate to protect wideband receivers (such as those used in MMDS networks) from harmful interference caused by UWB transmitters. In this regard, Cisco agrees with WINForum that the interference effect on such wideband receivers from UWB devices would be far greater than what would be predicted from conventional measurements using a 1 MHz filter.[14] Instead, the Commission should develop interference protection rules based upon the **energy spectral density** of the UWB transmissions which takes into account both the pulse size and the pulse repetition rate. As set forth below and in the attached materials, energy spectral density is a far better predictor of interference into victim receivers than peak and/or average power levels of UWB signals.

A. The Proposed Part 15 Interference Protection Rules Are Inadequate to Protect MMDS Broadband Wireless Systems

The shortcomings of the Commission's proposed interference protection rules for UWB devices become apparent when WINForum's analytical framework is applied to determine

---

[12] Comments of the Wireless Information Networks Forum, ET Docket No. 98-153 (Dec. 7, 1998).

[13] *In the Matter of Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, 13 FCC Rcd 16376, Notice of Inquiry, ET Docket No. 98-153, FCC 98-208 (rel. Sept. 1, 1998).

[14] Comments of the WINForum, Attachment 1, p. 6.

the interference potential of UWB signals to receivers used for broadband wireless communication systems such as MMDS equipment. One clear example of these deficiencies is the potential for large UWB signal peaks to corrupt digital communication symbols. Attachment 2 to these Comments includes an analysis demonstrating that under the Commission's proposed rules for peak power limits, a 12 MHz bandwidth MMDS receiver could experience peak UWB interference power as much as **44dB** higher than the levels used to measure compliance with the Part 15 limits (using a device to measure average power in a 1 MHz resolution bandwidth). Such large peaks will almost certainly cause significant numbers of bit errors for every pulse even at quite large separation distances between the UWB equipment and victim receivers.

The Commission's proposed average power limits are also problematic, particularly when the likely aggregate impact resulting from the proliferation of UWB devices is taken into account in determining interference effects. Attachment 3 to these Comments includes an analysis showing how one UWB device operating in accordance with the proposed rules and several hundred meters away from an MMDS receiver would cause a significant and unacceptable increase in that receiver's noise floor. When the aggregate effects of multiple UWB devices are taken into consideration, the same impact on the MMDS receiver noise floor would be achieved with even further separation distances. For example, a single UWB transmitter just 20 meters away from an MMDS receiver or 100 UWB transmitters 200 meters away from an MMDS receiver would cause a 20 dB increase in the noise floor experienced by the MMDS receiver.[15] The graphs in Attachment 3 depict the results of this analysis for varying numbers of UWB devices at various separation distances.

---

[15] This latter scenario could correspond to an MMDS base station located near a highway traveled by automobiles equipped with UWB collision avoidance radars.

B. Energy Spectral Density is a Superior Measure of Potential Interference from UWB Devices into Wideband Communications Receivers

As shown above, the use of the peak and average power limits in Part 15 of the Rules is inadequate to protect communications systems using wideband receivers from unacceptable levels of UWB interference. The rules governing UWB devices must be structured with the protection of existing wireless services as a major objective. Therefore, the correct approach should be to analyze and measure the response of victim receivers to UWB transmissions and use the results of such an analysis to guide the Commission in shaping the rules.

WINForum undertook such an analysis to determine the impact of various types of UWB devices, including those with constant inter-pulse intervals, those with pulse position modulation, and those with random or pseudorandom inter-pulse intervals. As the WINForum submission correctly illustrated, the response of a victim receiver is proportional to the **energy spectral density** of an individual UWB pulse for all of the aforementioned UWB signal types. Depending on the type of modulation used in the UWB system, the victim receiver response is also a function of its receiver bandwidth, the average repetition rate of the UWB pulses, or both. Thus, the victim receiver response does not depend directly on the peak power of the pulse, nor on the total energy in the pulse, or on power spectral density.[16] Power spectral density is

---

[16] In the limited case where the UWB system employs constant inter-pulse intervals and the pulse repetition rate is high relative to the receiver bandwidth, the victim receiver response can be simplified as a function of the power spectral density of the UWB transmissions. However, this is a special case and expressing the victim receiver response in terms of the UWB transmitter's energy spectral density and the pulse repetition rate is still valid.

inherently an <u>average</u> measure. It cannot account for the effects of relatively large and infrequent UWB pulses, a situation that could result in a modest power spectral density at any given frequency but, at the same time, have a very detrimental effect on a victim receiver. Similarly, specifying peak power in the time domain does not account for the way the energy is distributed in the frequency domain. Therefore, specifying energy spectral density, in conjunction with pulse repetition rate, is a superior method for ensuring that UWB systems do not harm existing radio services.

While WINForum showed the importance of <u>energy</u> spectral density in determining a UWB device's potential to cause interference, some of their conclusions seem to advocate instituting <u>power</u> spectral density limits, an apparent inconsistency. Upon closer examination, however, it appears that WINForum remains consistent with the idea that power spectral density, as traditionally defined, is not sufficient to control UWB interference to victim receivers. WINForum recognized that a "reasonable measure of the effect of interference is the amount by which it raises the effective noise floor of the victim receiver."[17] It then expressed this metric as the ratio of interfering power to the victim receiver bandwidth (P_{int}/B_h) and termed this quantity an "effective power spectral density." The interfering power (P_{int}) can refer to average or peak power depending on the context. While this quantity is an excellent measure of the impact of interference, and while it has the same units as power spectral density (power per unit bandwidth), it is not the same as power spectral density as that term is generally accepted.[18]

---

17 *See* WINForum Comments at Attachment 1, p.3.

18 The accepted definition of power spectral density is the Fourier transform of the autocorrelation function of a time-domain waveform, with the autocorrelation integral taken over all time for waveforms with finite energy or over one period for periodic waveforms (in the case of the generalized autocorrelation function).

Furthermore, the WINForum recommendation to specify power spectral density *and have it be measured over a range of receiver bandwidths* evidences that power spectral density does not sufficiently control the interference potential of UWB devices.[19] Specifying power spectral density over a range of receiver bandwidths accomplishes, though not as succinctly, the same goal as an energy spectral density limit which limits interference to known levels across a range of pertinent victim receiver implementations. The precise energy spectral density limits will depend on the range of bandwidths of victim receivers that should be protected, and will likely be a function of the pulse repetition frequency of the UWB device.

III. THE COMMISSION MUST CONSIDER ACTUAL TESTS OF UWB DEVICES WITH WIDEBAND COMMUNICATIONS SYSTEMS

In light of the analysis done to date on the potential for harmful interference from UWB devices to wideband communications systems, such as MMDS networks, significant testing must be done before any interference protection rules can be adopted by the Commission. While the Commission recognizes that such testing is necessary in order to protect various safety services in restricted bands, such as GPS, there are equally compelling reasons to conduct similar test programs for important commercial communications networks, including Internet access technologies.

The Commission has recognized the importance of two-way broadband digital MMDS. As a result of a recent series of changes in the Commission's Rules, MMDS and ITFS providers have been authorized to use their spectrum for two-way digital services. In August

---

[19] *See* WINForum Comments at Attachment 1, pp. 5-6.

2000, the Commission opened a filing window[20] and it expects that "the resultant authorization of two-way MDS operations will speed the deployment of advanced services by permitting service providers to offer a variety of fixed wireless high-speed services more rapidly."[21] A number of MMDS operators are now in the process of deploying broadband fixed wireless systems that will compete directly with cable and DSL offerings.[22] Analysts predict that broadband fixed wireless equipment will be deployed in approximately 4.4 million homes and offices in the United States alone by 2004. This deployment will accelerate the spread of advanced service capabilities and, perhaps more importantly, bring broadband Internet access to many areas unserved or underserved by existing technologies.

In order to fulfill the promise of MMDS, however, the Commission must not authorize any new services that have the potential to cause destructive interference to fixed

---

[20] *See Public Notice*, "Commission Announces Initial Filing Window for Two-Way Multipoint Distribution Service and Instructional Television Fixed Service," 15 FCC Rcd 5850, DA 00-666 (Mar. 23, 2000); *see also In the Matters of ITFS 2020 Emergency Petition for Postponement of the July 3 – July 10, 2000 Filing Window for Two-Way Multipoint Distribution Service and Instructional Television Fixed Service Applications and The Association of Federal Communications Consulting Engineers Petition Requesting Revision of Initial Filing Window for Two-Way Multipoint Distribution and Instructional Television Fixed Service*, 15 FCC Rcd 10912, Order, MM Docket No. 97-217 (rel. June 23, 2000).

[21] *See In the Matter of Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans In a Reasonable and Timely Fashion, And Possible Steps to Accelerate Such Deployment Pursuant to Section 706 of the Telecommunications Act of 1996*, Second Report, CC Docket. No. 98-146, FCC 00-290, at ¶ 263 (rel. Aug. 21, 2000).

[22] *See e.g.*, www.wcom.com/about_the_company/press_ releases (Aug. 14, 2000 press release discussing Worldcom's plans for licensing and deployment in 60 markets nationwide); www3.sprint.com/PR/CDA/PR_CDA_Press_Releases_Detail/ 1,1694,2004,00.html (Aug. 22, 2000 press release discussing Sprint's filing of a series of applications with the FCC to offer fixed wireless broadband service in 45 U.S. markets).

wireless broadband networks. In this regard, it is critical that further testing and analysis be conducted before any rules are adopted in this proceeding.

IV. CONCLUSIONS

For the reasons set forth in these Comments, Cisco Systems, Inc. urges the Commission to consider carefully the potential for interference from UWB devices into commercial fixed wireless networks, such as those in the MMDS bands, so that it can adequately protect these important communications services from interference. Among the issues that must be further explored are: (1) the potential interference impacts of large UWB signal peaks into existing systems; (2) limitations of 1 MHz interference measurements when broadband services are being impacted; (3) regulatory limits based on **energy spectral density** and pulse repetition frequency rather than power spectral density; and (4) the aggregation effects of large numbers of UWB devices operating in a single area. Furthermore, all of these matters would benefit from further testing of UWB interference into commercial radio systems, including fixed wireless broadband systems.

Respectfully submitted

CISCO SYSTEMS, INC.

By: ______________________

Philip L. Malet
Todd B. Lantor
Steptoe & Johnson LLP
1330 Connecticut Avenue, N.W.
Washington, DC 20036
(202) 429-3000

Counsel for Cisco Systems, Inc.

Bruce Mehlman
Telecommunications Policy Counsel
Cisco Systems, Inc.
601 Pennsylvania Ave., N.W.
Suite 520 – North Building
Washington, DC 20004
(202) 661-4006

Dated: September 12, 2000

Attachment 1

ANALYTICAL FRAMEWORK FOR STUDYING THE EFFECTS OF UWB DEVICES ON VICTIM RADIO RECEIVERS

The basic framework for studying the effects of UWB devices is set forth in the Comments of the WINForum in response to the Commission's *Notice of Inquiry* (Comments of the WINForum, Attachment 1, pp. 1-2, ET Docket No. 98-153 (Dec. 7, 1998)).

A UWB signal can be modeled as a very short duration pulse that repeats at R_P pulses per second. The resulting spectrum will be a series of spectral lines at frequencies that are multiples of the pulse rate. The victim receiver has a filter of bandwidth B_h which is much less than the bandwidth of the pulse. The filter has a center frequency f_0 and the energy spectral density of the pulse at that frequency is denoted by $\Phi(f_0)$. The output of the filter in response to the pulse characterizes the interference of the UWB signal to the victim receiver.

The resulting interference can then be modeled for four different cases:

[1] If the pulse is repeated at regular intervals (no variation in the time between pulses), then the spectrum of the UWB signal consists of spectral lines at frequencies that are multiples of R_P. The power in the spectral component at frequency kR_P is $\Phi(kR_P)R_P^2$. This is the power output of a filter that is narrow enough to resolve the spectral lines; *i.e.*, $B_h < R_P$. Stated in terms of the time domain, the filter response time exceeds the inter-pulse interval, so the filter output is due to the combined effect of multiple UWB pulses.

[2] If the inter-pulse interval is varied randomly and $B_h << \overline{R}_P$ (where $\overline{R}_P$ is the average repetition rate), the filter output will have a probability distribution approaching that of Gaussian noise, with average power $\Phi(f_0)B_h\overline{R}_P$. As the filter bandwidth B_h approaches the pulse rate, the filter output will become less noise-like. For a filter bandwidth that exceeds the pulse rate, case [4] below applies.

[3] If pulse-position modulation (PPM) is used with an average pulse rate $\overline{R}_P$, and $B_h < \overline{R}_P$, there will in general be spectral lines of varying strengths at some frequencies that are integer multiples of $\overline{R}_P$, and the strongest lines will have power $\Phi(k\overline{R}_P)\overline{R}_P^2$. The positions and strengths of the spectral lines depend on the pulse-position deviation relative to the nominal inter-pulse interval $1/\overline{R}_P$.

[4] If the filter bandwidth exceeds the pulse rate (regardless of the pulse repetition discipline), then the filter responds to each pulse individually, or in frequency-domain terms, the filter bandwidth spans multiple spectral lines and cannot resolve them. In this case, the filter power output is $\Phi(f_0)B_h^2$. This is the average power output over the filter response time. The absolute peak envelope power is about 3 dB higher, due to peaking of the filter impulse response. The quantity $\Phi(f_0)B_h^2$ appears to be the appropriate measure of interference potential, since if it is large enough it will cause a symbol error in the victim receiver. The effect of these symbol errors will depend on the nature of the system supported by the victim receiver as well as the rate at which the errors occur, but in some cases, periodic bit errors could effectively cause link failure.

In summary, it can be seen that the interference potential of the UWB signal is largely a function of its energy spectral density and pulse repetition frequency. By contrast, the FCC's proposed approach is based largely on the current Part 15 Rules and, therefore, focuses on average power and peak power. Also, the Part 15 Rules use a 1 MHz measurement bandwidth to determine acceptable radiated power whereas a wideband receiver may have a larger bandwidth that may encompass multiple spectral peaks of a UWB signal.

Method For Calculating Maximum Permissible Energy Spectral Density

$\Phi_g(f_0)$ is the energy power spectral density (ESD) of a UWB pulse, g(t).

$$\Phi_g(f_0) \equiv 2|G(f_0)|^2$$

where,

$$G(f_0) = \int_{-\infty}^{\infty} g(t) e^{-j2\pi ft} dt, \text{ the Fourier Transform of } g(t)$$

The ESD and interfering power are related by the following formula:

$$P_{UWB} = \Phi_g(f_0)\, BW^2$$

where,

BW^2 is a bandwidth (squared) scaling factor that depends on the UWB waveform and/or the victim receiver bandwidth. This is explained in greater detail below.

In order to calculate the tolerable ESD one must determine the maximum value of P_{UWB} that will result in minimal impact to existing licensed receivers. Since the UWB device's ability to interfere is a function of the output power and its transmit antenna gain, one can solve for the UWB devices' effective isotropic radiated power ($EIRP_{UWB}$) instead.

$$EIRP_{UWB\ max} = P_{int\ max} - G_r - L - C_{agg}$$

where,

$P_{int\ max}$ = the maximum tolerable interference power at the victim receiver, [dBm]

G_r = the gain of the victim receive antenna, [dB]

L = the free space path loss between UWB device and the victim receiver, [dB]

C_{agg} = the correction factor for multiple UWB devices falling within the main beam of the victim receive antenna, [dB]

Going to the next level of detail, several of the variables given above may be further described as follows:

$$P_{int\_max} = kTB - \Delta$$

where,

Δ = the noise floor protection factor. This factor is designed to control the rise in the effective victim receiver noise floor to an acceptable level. If $\Delta = 10$ dB, then by holding the aggregate interfering power 10 dB below the ambient thermal noise floor will result in a rise in the noise floor of no more than 0.5 dB.

And,

$$L = \left(\frac{\lambda}{4 \pi D} \right)^2$$

where,

λ = the RF wavelength at the victim receiver's RF center frequency

D = the minimum separation distance between UWB transmitter and victim receiver at which one would desire minimal interference to the victim receiver.

And,

$$Cagg = 10 \log(N_{UWB})$$

where,

N_{UWB} = the number of UWB devices falling in the main beam of the victim receiver antenna. (For simplicity, the signals of various UWB devices are assumed to add incoherently.)

Finally, the factor BW^2 must be defined. This variable will take on different values depending on the structure of the UWB transmissions. The following table lists the pertinent cases.

	UWB transmit signal structure	BW^2	Comments
1	periodic pulses, pulse position modulation, or random inter-pulse intervals, with $R_p < B_h$ or $\overline{R}_p < B_h$	$(1.44B_h)^2$	When the victim receiver bandwidth is greater than the (average) pulse repetition rate, the victim receiver responds to individual UWB pulses.
2	periodic pulses, with $R_p >> B_h$	R_p^2	The victim receiver resolves the discrete frequency tones (arising from the periodic time-domain waveform) and responds to the single tone which falls in the victim receiver bandwidth.
3	pulse sequence with random inter-pulse intervals $R_p >> B_h$	$\overline{R}_p B_h$	The victim receiver response to the UWB signal is a bandpass Gaussian process.
4	pulse position modulated sequence with $R_p >> B_h$	R_p^2	The victim receiver resolves the discrete frequency tones (arising from the periodic time-domain waveform) and responds to the single tone which falls in the victim receiver bandwidth.

Attachment 2

ANALYSIS OF UWB SIGNAL PEAKS INTO MMDS RECEIVERS

Under the proposed rules, UWB devices can transmit large and irregular pulses while staying well below the proposed limits on average transmit power. Consistent with the existing Part 15 approach, the proposed rules set permissible UWB transmit power with reference to a hypothetical 1 MHz bandwidth certification receiver. The average interference power experienced by the certification receiver is given by:

$$\overline{P}_{rx} = \Phi_g(f_0)\overline{R}_p B_h \,, \quad B_h = 1\ MHz$$

where $\Phi_g(f_0)$ is the energy spectral density of the pulse at frequency f_0, $\overline{R}_p$ is the average pulse repetition frequency, and B_h is the receiver bandwidth. For the same UWB signal, the peak interference power received by a 12 MHz victim receiver is given by:

$$P_{rx\_pk} = \Phi_g(f_0)(\kappa B_h)^2 \,, \quad B_h = 12\ MHz$$

where κ is a constant, 1.44. The ratio of the peak power received by the 12 MHz receiver to the average power received by the certification receiver is:

$$\frac{P_{rx\_peak}(12\ MHz)}{\overline{P}_{rx}(1\ MHz)} = \frac{\Phi_g(f_0)(\kappa \cdot 12 \cdot 10^6)^2}{\Phi_g(f_0)\overline{R}_p 10^6} = \frac{\Phi_g(f_0)(1.44 \cdot 12 \cdot 10^6)^2}{\Phi_g(f_0)\overline{R}_p 10^6}$$

$$= 84.7\ dB + 10\log_{10}\left(\overline{R}_p^{\,-1}\right)$$

For modulated rectangular pulses, the peak to average power ratio is given as:

$$\frac{P_{UWB\_pk}}{\overline{P}_{UWB}} = \frac{T}{\tau} = \left(\tau \cdot \overline{R}_p\right)^{-1}, \quad \tau = pulse\ width$$

where T is the inter-pulse period and τ is the pulse width. According to the proposed rules (*NPRM*, ¶ 43), the limit on peak to average power is given by:

$$\frac{P_{pk}}{\overline{P}} = 20 + 20\log_{10}\left(\frac{BW_{(-10dB)}}{50\ MHz}\right) \approx 20 + 20\log_{10}\left(\frac{1.5\ GHz}{50\ MHz}\right), \ for\ \tau = 1\,nsec$$

$$= 49.4\ dB = 87{,}000$$

Then, the minimum permissible pulse repetition frequency that will satisfy this constraint on peak to average power is given as:

$$(\tau \cdot R_p)^{-1} = 87{,}000 \;\Rightarrow\; R_p = (\tau \cdot 87{,}000)^{-1} = 11.5\ kHz$$

At a pulse repetition frequency of 11.5 kHz, the ratio of peak power experienced by the 12 MHz victim receiver to average power experienced by the certification receiver is given by:

$$\frac{P_{rx\_peak}(12\ MHz)}{\overline{P}_{rx}(1\ MHz)} = 84.7\ dB - 10\log_{10}(11.5 \cdot 10^3) = 44.1\ dB$$

In this case, which is not even the worst case scenario, in order to avoid interference, UWB devices and MMDS receivers would have to be separated by at least the radio horizon -- on the order of 25-30 miles. The discrepancy between the peak power seen by a wideband victim receiver and the average power measured in a 1 MHz bandwidth becomes even larger when the UWB 10 dB bandwidth increases to at least 5 GHz, and a peak-to-average power ratio of 60 dB is permitted. In that case, R_P becomes 1kHz and the ratio of peak power experienced by the 12 MHz victim receiver to average power experienced by the certification receiver is 54.7 dB.

Attachment 3

ANALYSIS OF UWB AVERAGE POWER LIMITS ON MMDS RECEIVERS

Consider the interference impact of a UWB device which transmits periodic pulses modulating a sinusoidal carrier with a center frequency of 2.5 GHz, coincident with that of the victim receiver.[1] The MMDS receiver has a bandwidth of 12 MHz. The UWB pulse width is τ=1 ns, and the pulse repetition frequency is 20 MHz. The power spectral density of this UWB signal consists of discrete spectral lines spaced by 20 MHz and has the envelope $\sin(\pi\tau(f-f_0))/(\pi\tau(f-f_0))$. Assume that the UWB device emits the maximum available power allowable under the proposed rules, which at this frequency is an EIRP of -41 dBm as measured in a 1 MHz resolution bandwidth. Consistent with Cisco Systems, Inc.'s MMDS products, an antenna gain of 20 dBi is assumed. In this case, since the receiver's bandwidth is wider than the pulse repetition frequency and the spacing of the UWB spectral peaks, the victim receiver will experience a single spectral peak. The minimum separation distance between this UWB transmitter and victim MMDS receiver that assures proper operation of the MMDS receiver can now be computed.

First, the received UWB interfering signal power is calculated as follows:

$$P_{rx} = EIRP - L_{path} + G_{rx}$$

where,

L_{path} = propagation loss in free space

G_{rx} = receive antenna gain

$$P_{rx} = -41 + 20 \cdot \log_{10}\left(\lambda / 4\pi D\right) + 20 \quad [dBm]$$

where,

D = separation in meters

λ = wavelength at 2.5 GHz

$$P_{rx} = -61.4 - 20 \cdot \log_{10}(D) \quad [dBm]$$

[1] As problematic as the results in this Attachment are, it should be noted that the UWB waveform used as a basis for this analysis has not been selected to be the worst case.

To assure that the MMDS receiver continues to operate as designed for the intended signals, assume that the UWB interfering signal power arrives at the victim receiver 10 dB below the noise floor so that the noise floor is raised by no more than 0.5 dB. This seemingly small elevation of the noise floor will require a 12 % increase in transmitter power to overcome the increased interference. The minimum required separation distance D can then be calculated as:

$$P_{rx} \leq kT + 10 \cdot \log_{10}(B) - 10 \quad [dBm]$$

$$\therefore$$

$$-61.6 - 20 \cdot \log_{10}(D) \leq -174 + 70.8 - 10$$

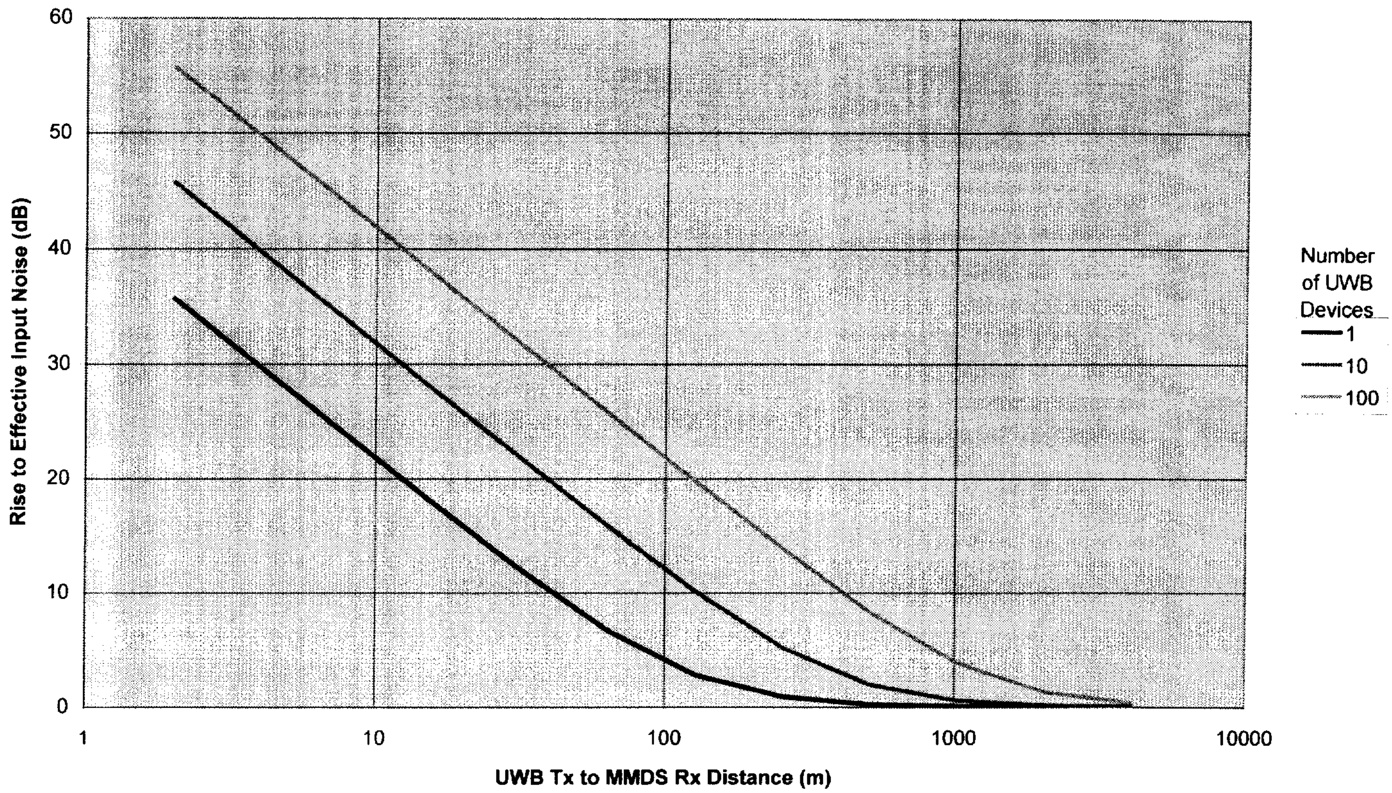
or,

$$D \geq 10^{51.6/20} = 380 \text{ m}$$

Note that this distance corresponds to a <u>single</u> UWB device. Aggregation effects must also be considered. UWB proponents anticipate applications such as collision avoidance radar and data networking which would involve large numbers of simultaneously transmitting UWB devices. An optimistic but reasonable assumption is that the interference powers add incoherently. If 10 devices fall within the victim receiver's main antenna beam, the received power is 10 times larger, and the UWB devices must be 3.2 times farther away (at least 1.2 km) to avoid causing harmful interference. If 100 UWB devices fall within the victim receiver's main antenna beam, UWB devices must be 10 times farther away (at least 3.9 km) to avoid causing harmful interference.

The following graph (Chart 1) shows the increase to the victim receiver noise floor caused by 1, 10, or 100 UWB devices emitting at the FCC's proposed power limit over a range of distances to the MMDS receiver.

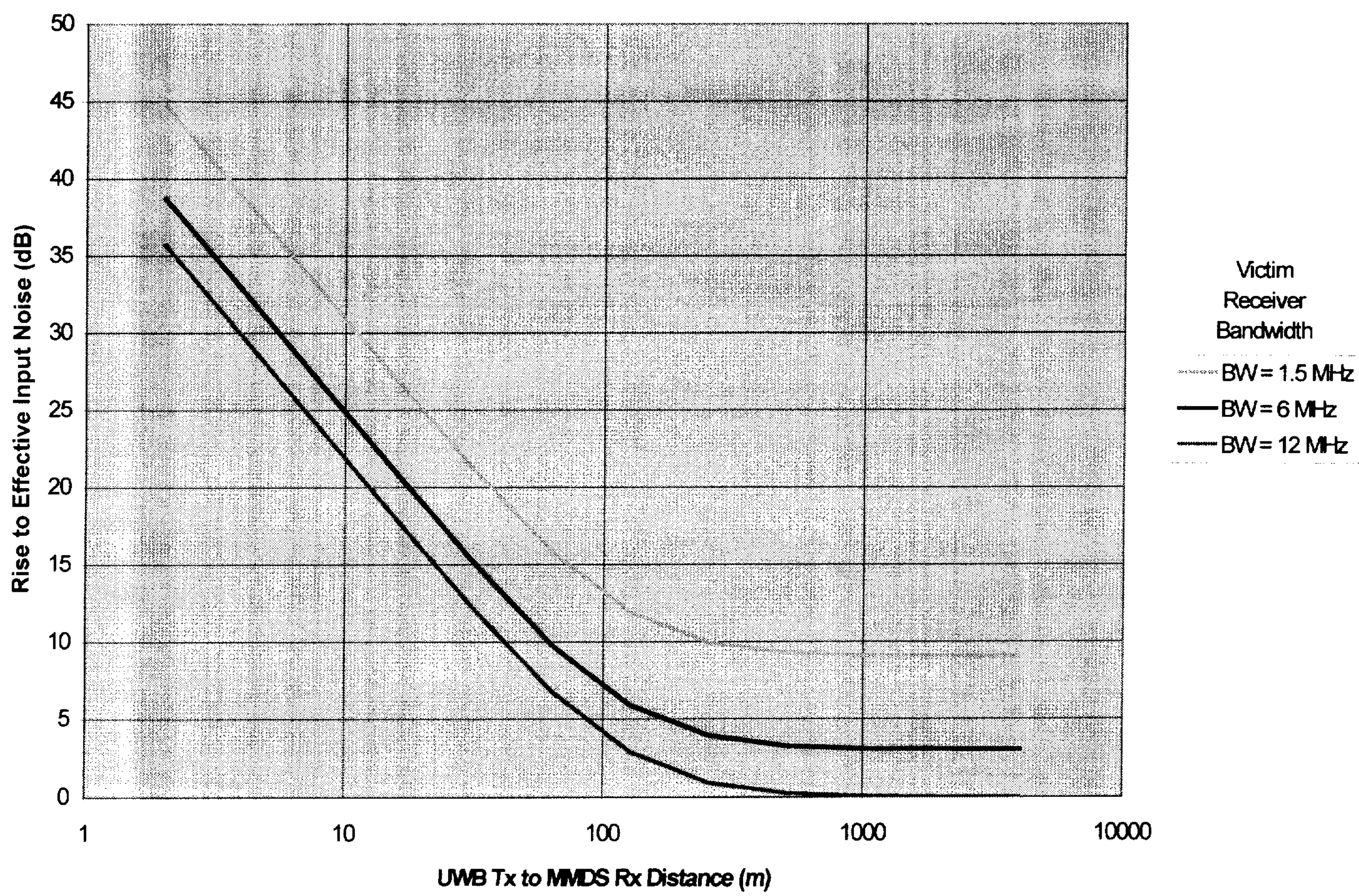
Victim Receiver Noise Floor Increase for 1, 10, and 100 UWB Devices
(Example 1, Periodic Pulses)



It can be seen that 10 UWB devices at a range of 390 meters will cause a 3 dB increase in the noise floor level. Overcoming this elevation will require at lease a doubling of MMDS transmitter output power capability. Cisco estimates a 50% increase in the cost of the customer equipment to develop this increased output power.

For additional reference, the following graph (Chart 2) shows the increase to the noise floor caused by 1 UWB device over a range of distances and several possible MMDS receiver bandwidths.

Victim Receiver Noise Floor Increase for 1.5, 6, and 12 MHz Receiver Bandwidths (Example 1, Periodic Pulses, Single UWB Tx)



Data Points for Chart 1

Chart Receiver Noise Floor Increase for 1, 10, and 100 UWB Devices

Parameter name	Value	Units
Bh	12,000,000	Hz
kTB	-103.2	dBm
Gr	20.0	dBi
f0	2.5	GHz
eirp	-41.0	dBm

Distance	Path Loss	Nuwb	Puwb	New Noise Floor	delta noise	
2.00	-46.4	1	-67.4	-67.4	35.78	1.0
4.00	-52.4	1	-73.4	-73.4	29.76	2.0
8.00	-58.5	1	-79.5	-79.5	23.76	3.0
16.00	-64.5	1	-85.5	-85.4	17.79	4.0
32.00	-70.5	1	-91.5	-91.2	11.98	5.0
64.00	-76.5	1	-97.5	-96.5	6.72	6.0
128.00	-82.6	1	-103.6	-100.4	2.84	7.0
256.00	-88.6	1	-109.6	-102.3	0.90	8.0
512.00	-94.6	1	-115.6	-103.0	0.24	9.0
1024.00	-100.6	1	-121.6	-103.1	0.06	10.0
2048.00	-106.6	1	-127.6	-103.2	0.02	11.0
4096.00	-112.7	1	-133.7	-103.2	0.00	12.0
2.00	-46.4	10	-57.4	-57.4	45.78	1.0
4.00	-52.4	10	-63.4	-63.4	39.76	2.0
8.00	-58.5	10	-69.5	-69.5	33.74	3.0
16.00	-64.5	10	-75.5	-75.5	27.73	4.0
32.00	-70.5	10	-81.5	-81.5	21.73	5.0
64.00	-76.5	10	-87.5	-87.4	15.79	6.0
128.00	-82.6	10	-93.6	-93.1	10.10	7.0
256.00	-88.6	10	-99.6	-98.0	5.20	8.0
512.00	-94.6	10	-105.6	-101.2	1.98	9.0
1024.00	-100.6	10	-111.6	-102.6	0.59	10.0
2048.00	-106.6	10	-117.6	-103.1	0.15	11.0
4096.00	-112.7	10	-123.7	-103.2	0.04	12.0
2.00	-46.4	100	-47.4	-47.4	55.78	1.0
4.00	-52.4	100	-53.4	-53.4	49.76	2.0
8.00	-58.5	100	-59.5	-59.5	43.74	3.0

16.00	-64.5	100	-65.5	-65.5	37.72	4.0
32.00	-70.5	100	-71.5	-71.5	31.70	5.0
64.00	-76.5	100	-77.5	-77.5	25.69	6.0
128.00	-82.6	100	-83.6	-83.5	19.70	7.0
256.00	-88.6	100	-89.6	-89.4	13.82	8.0
512.00	-94.6	100	-95.6	-94.9	8.31	9.0
1024.00	-100.6	100	-101.6	-99.3	3.88	10.0
2048.00	-106.6	100	-107.6	-101.9	1.34	11.0
4096.00	-112.7	100	-113.7	-102.8	0.38	12.0

Data Points for Chart 2

Victim Receiver Noise Increase for 1.5, 6, and 12 MHz Receiver Bandwidths

Parameter name	Value	Units
kTB	#NAME?	dBm
Gr	20.0	dBi
f0	2.5	GHz
eirp	-41.0	dBm
Nuwb	1.0	

Distance	Path Loss	Bh	Puwb	New Noise Floor	delta noise	
2.00	-46.4	1.50E+06	-67.4	-67.4	44.81	1.0
4.00	-52.4	1500000	-73.4	-73.4	38.80	2.0
8.00	-58.5	1500000	-79.5	-79.5	32.79	3.0
16.00	-64.5	1500000	-85.5	-85.4	26.82	4.0
32.00	-70.5	1500000	-91.5	-91.2	21.01	5.0
64.00	-76.5	1500000	-97.5	-96.5	15.75	6.0
128.00	-82.6	1500000	-103.6	-100.4	11.87	7.0
256.00	-88.6	1500000	-109.6	-102.3	9.93	8.0
512.00	-94.6	1500000	-115.6	-103.0	9.27	9.0
1024.00	-100.6	1500000	-121.6	-103.1	9.09	10.0
2048.00	-106.6	1500000	-127.6	-103.2	9.05	11.0
4096.00	-112.7	1500000	-133.7	-103.2	9.03	12.0
2.00	-46.4	6.00E+06	-67.4	-67.4	38.79	1.0
4.00	-52.4	6000000	-73.4	-73.4	32.78	2.0
8.00	-58.5	6000000	-79.5	-79.5	26.77	3.0
16.00	-64.5	6000000	-85.5	-85.4	20.80	4.0
32.00	-70.5	6000000	-91.5	-91.2	14.99	5.0
64.00	-76.5	6000000	-97.5	-96.5	9.73	6.0
128.00	-82.6	6000000	-103.6	-100.4	5.85	7.0
256.00	-88.6	6000000	-109.6	-102.3	3.91	8.0
512.00	-94.6	6000000	-115.6	-103.0	3.25	9.0
1024.00	-100.6	6000000	-121.6	-103.1	3.07	10.0
2048.00	-106.6	6000000	-127.6	-103.2	3.03	11.0
4096.00	-112.7	6000000	-133.7	-103.2	3.01	12.0
2.00	-46.4	1.20E+07	-67.4	-67.4	35.78	1.0
4.00	-52.4	12000000	-73.4	-73.4	29.76	2.0
8.00	-58.5	12000000	-79.5	-79.5	23.76	3.0
16.00	-64.5	12000000	-85.5	-85.4	17.79	4.0

32.00	-70.5	12000000	-91.5	-91.2	11.98	5.0
64.00	-76.5	12000000	-97.5	-96.5	6.72	6.0
128.00	-82.6	12000000	-103.6	-100.4	2.84	7.0
256.00	-88.6	12000000	-109.6	-102.3	0.90	8.0
512.00	-94.6	12000000	-115.6	-103.0	0.24	9.0
1024.00	-100.6	12000000	-121.6	-103.1	0.06	10.0
2048.00	-106.6	12000000	-127.6	-103.2	0.02	11.0
4096.00	-112.7	12000000	-133.7	-103.2	0.00	12.0

ENGINEERING CERTIFICATION

I, Michael Pollack, hereby certify that I am familiar with Part 15 of the Commission's Rules, that I have either prepared or reviewed the engineering information contained in the Comments and Attachments filed by Cisco Systems, Inc. in ET Docket No. 98-153, and that said information is complete and accurate to the best of my knowledge and belief.

By: Michael Pollack

Michael Pollack
Wireless Systems Engineer
Wireless Access Business Unit
Cisco Systems, Inc.

Date: 9/11/2000